*SCHAUM'S OUTLINE OF*

# THEORY AND PROBLEMS

of

# MICROPROCESSOR FUNDAMENTALS

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by

ROGER L. TOKHEIM, M.S.

*Chairman, Department of Industrial Education*
*Henry Sibley High School*
*Mendota Heights, Minnesota*

**SCHAUM'S OUTLINE SERIES**

McGRAW-HILL BOOK COMPANY

*New York St. Louis San Francisco Auckland Bogotá Guatemala Hamburg Johannesburg*
*Lisbon London Madrid Mexico Montreal New Delhi Panama Paris*
*San Juan São Paulo Singapore Sydney Tokyo Toronto*

ROGER L. TOKHEIM holds B.S. and M.S. degrees in Industrial Arts Education from St. Cloud State College and an Ed.S. degree in Vocational Education from the University of Wisconsin–Stout. He is the author of *Schaum's Outline of Digital Principles* (McGraw-Hill, 1980), *Digital Electronics* (McGraw-Hill, 1979), and numerous other instructional materials on science and industry. An experienced educator at the adult and secondary levels, he is presently an Instructor of Industrial Education at Henry Sibley High School, Mendota Heights, Minnesota.

Schaum's Outline of Theory and Problems of
MICROPROCESSOR FUNDAMENTALS



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 SHP SHP 8 7 6 5 4 3

ISBN 0-07-064958-8

Sponsoring Editor, John Aliano
Editing Supervisor, Marthe Grice
Production Manager, Nick Monti

**Library of Congress Cataloging in Publication Data**

Tokheim, Roger L.
Schaum's outline of theory and problems of microprocessor fundamentals.

(Schaum's outline series)
Includes index.
1. Microprocessors. 2. Microprocessors--Problems, exercises, etc. I. Title.
QA76.5.T559 1983 001.64 82-9889
ISBN 0-07-064958-8 AACR2

# Preface

The electronics student or specialist of tomorrow must have a knowledge of microprocessors and microprocessor-based systems. This will include knowledge not only of microcomputer hardware but of software as well. Microprocessors are the basis for an entire new breed of intelligent devices or machines. Microprocessors will be found in diverse products: from children's toys to word processors, from pocket computers to home appliances, from industrial robots to home thermostats. Due to programmable devices called microprocessors, the development of intelligent machines is expected to accelerate in the future.

*Schaum's Outline of Microprocessor Fundamentals* provides the reader with the basic topics customarily covered in a first course in microprocessors. The Schaum's Outline philosophy of concentrating on typical problems encountered while studying any subject is supported in this outline by the use of over 1000 practical microprocessor and microcomputer problems. Complete solutions accompany most of the problems used in this book.

The topics outlined in this book were carefully selected to coincide with courses taught at the upper high school, vocational-technical, and community college level. Many of the most widely used vocational-technical level textbooks and lab manuals on microprocessors and microcomputers were analyzed. The topics and problems included in this Schaum's Outline are similar to those encountered most frequently in these standard books. Program segments listed in this outline were carefully checked for accuracy on typical inexpensive microcomputer trainers.

The *Schaum's Outline of Microprocessor Fundamentals* begins with a short introduction to computers. Next background information on numbers, computer codes, and computer arithmetic is presented along with a review of basic digital devices. Commercial microprocessor based systems are very complex. Because of this a simplified generic microprocessor is used to introduce microcomputer fundamentals, the microprocessor, programming the microprocessor, and interfacing the microprocessor. Then the widely used Intel 8080/8085 microprocessor is detailed with a companion chapter on programming the 8080/8085 microprocessor. Finally, the common Motorola 6800 microprocessor is covered with an associated chapter on programming the 6800 microprocessor. The similarity in microprocessor operation from processor to processor is stressed. Even the simplified generic microprocessor has characteristics of some of the most popular general-purpose microprocessors.

The Intel 8080 and 8085 microprocessors are featured because of their wide acceptance in both industry and training programs. The 8080/8085 is also very similar to the popular 8-bit Z80 microprocessor by Zilog and the powerful 16-bit

8086 and 8088 units developed by Intel. The 8088 processor is currently used in the versatile IBM personal computer. The 6800 microprocessor was selected because of its popular use in existing training systems and because it is a member of Motorola's well-supported 6800 family which includes the enhanced 8-bit 6809 and the 16-bit 68000 microprocessor.

Appreciation is extended to McGraw-Hill's John Aliano and to my students at Henry Sibley High School for their inspiration and assistance. Special thanks to my family, Caroline, Daniel, and Marshall, for their forbearance, good humor, and constant encouragement.

ROGER TOKHEIM

# Contents

# Chapter 1

# Introduction to Computers

## 1.1 INTRODUCTION

Computers have been in general use since the 1950s. Formerly, digital computers were large, expensive machines used by governments and large businesses. The size and shape of the digital computer has changed in the past few years owing to a new device called the microprocessor. The *microprocessor* is an IC (integrated circuit) that contains much of the processing capabilities of a large computer. The microprocessor is a small but extremely complex LSI (large-scale-integration) device that is programmable. Computers use a stored program. Smaller computers, called *microcomputers*, also use the *stored-program* concept. A microcomputer contains a microprocessor and at least some form of semiconductor memory.

Large, expensive computers are usually *general-purpose* units. They are typically reprogrammed and used for many jobs. *Dedicated computers* are becoming very common because of the use of the small, inexpensive microprocessor. A dedicated computer is programmed for and performs only one or two tasks, as in toys, thermostats, automobiles, microwave ovens, etc.

## 1.2 COMPUTER ORGANIZATION

The traditional sections of a digital computer are shown in Fig. 1-1. This organization of functional parts is many times called the *architecture* of the computer. The basic computer system consists of five units: the *input* unit, the *control* and *arithmetic* units (contained in the CPU, or central processing unit), the *memory* unit, and the *output* unit.

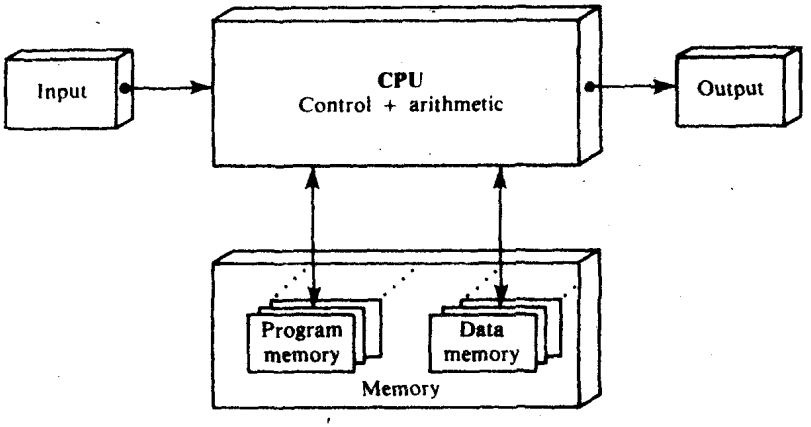


**Fig. 1-1** General organization of a computer

The physical units shown in boxes in Fig. 1-1 are referred to as *hardware*. To be useful, the *program memory* must tell the CPU what to do. Preparing the list of *instructions* is called *programming*. The list of instructions is a *program* and is stored either temporarily or permanently in the program memory. These programs manipulate information, called *data*. *Software* is a general term to cover all programs. If software is stored permanently in program memory, it is sometimes called *firmware*.

Briefly, the computer works in the following manner. Both program and data are fed into the CPU and transferred to their respective memory locations. The CPU reads the first instruction from program memory and executes it. Instructions may be as simple as ADD two numbers, MOVE data, INPUT or OUTPUT data, or JUMP to a different place in the program. After the data manipulations are complete, the results are transferred to the output of the computer. Again, most actions of the CPU are caused by the instructions stored in program memory.

SOLVED PROBLEMS

**1.1** List five functional sections of a digital computer.

**Solution:**

The five functional sections of a computer are shown in Fig. 1-1 as the input, control, arithmetic, memory, and output units. CPU is a general term for the unit that includes the control and arithmetic units as well as several other units.

**1.2** The organization of a system such as the one in Fig. 1-1 is sometimes referred to as the _____ of the computer.

**Solution:**

The organization of a system is sometimes referred to as the architecture of the computer.

**1.3** The actual electronic units such as those symbolized by the boxes in Fig. 1-1 are referred to as _____, while the programs instructing the computer what to do are called software.

**Solution:**

The actual physical electronic units in a computer are referred to as hardware.

**1.4** A person called a programmer writes a list of _____ which is called a program.

**Solution:**

A programmer writes a list of instructions which is called a program.

**1.5** List the two types of information that are input and stored in the memory of a computer.

**Solution:**

A program and data must be entered into the computer and stored in memory.

**1.6** Most of the actions of the CPU in a computer are caused by instructions stored in _____ memory.

**Solution:**

Most actions of the CPU are caused by instructions stored in program memory. Data to be processed is stored in data memory. In some computers, there is no physical difference between program memory and data memory.

## 1.3 MICROCOMPUTER ORGANIZATION

A microcomputer system is a digital computer. It is classed as a *micro* because of its small size and low cost. The *microprocessor* generally forms the CPU section of a microcomputer system. The organization of a typical microcomputer is diagramed in Fig. 1-2. The microcomputer contains all five basic sections of a computer: (1) the *input* unit, (2) the *control* and (3) *arithmetic* units contained within the microprocessor, (4) the *memory* unit, and (5) the *output* unit.

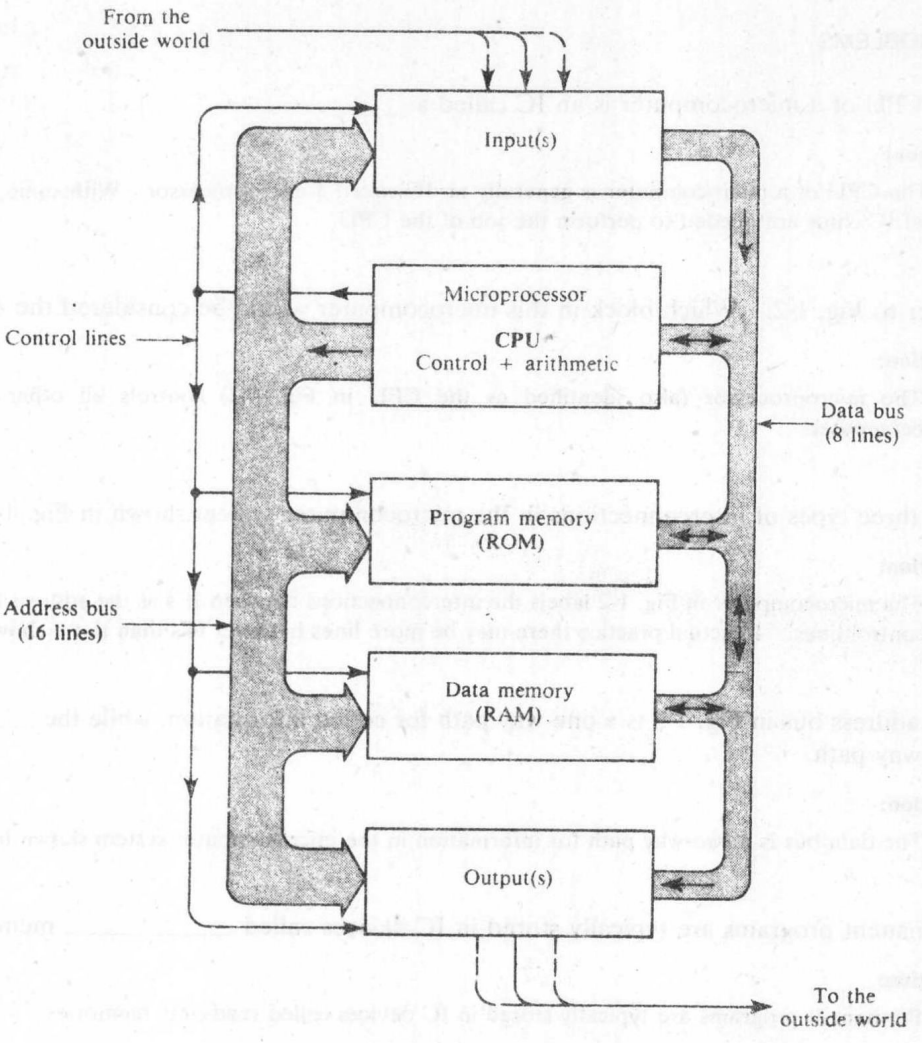


**Fig. 1-2** Typical microcomputer organization

The microprocessor controls all the units of the system using the *control lines* shown at the left in Fig. 1-2. Besides the control lines, the *address bus* (16 parallel conductors) selects a certain memory location, input port, or output port. The *data bus* (eight parallel conductors) on the right is a *two-way path* for transferring data in and out of the microprocessor unit. It is important to note that the microprocessor unit (MPU) can send data to or receive data from the memory using the data bus.

If a program is stored permanently, it is usually placed in a memory device called a *read-only memory* (ROM). The ROM (rhymes with "mom") is usually a permanently programmed memory chip (IC). Temporary data memory is usually stored in an IC device called a *read/write memory* (RWM). In common practice, the read/write memory is referred to as a *RAM* (rhymes with "jam"). Microcomputer user programs that are of a temporary nature are also stored in the RAM section of memory along with data. The RAM and ROM sections of memory are shown separate in Fig. 1-2 because they are usually separate ICs.

The system shown in Fig. 1-2 represents the general organization of a microcomputer. Most microcomputers would have these minimum features plus several more. For clarity, it is customary on block diagrams to omit the necessary power supply, clock, and some feedback lines to the microprocessor unit.

## SOLVED PROBLEMS

**1.7** The CPU of a microcomputer is an IC called a _____.

**Solution:**

The CPU of a microcomputer is generally an IC called a microprocessor. With some architectures, several IC chips are needed to perform the job of the CPU.

**1.8** Refer to Fig. 1-2. Which block in this microcomputer would be considered the *control* unit?

**Solution:**

The microprocessor (also identified as the CPU in Fig. 1-2) controls all other units in the microcomputer.

**1.9** List three types of interconnections in the microcomputer system shown in Fig. 1-2.

**Solution:**

The microcomputer in Fig. 1-2 labels the interconnections between ICs as the address bus, data bus, and control lines. In actual practice there may be more lines between ICs than those shown in Fig. 1-2.

**1.10** The address bus in Fig. 1-2 is a one-way path for coded information, while the _____ bus is a two-way path.

**Solution:**

The data bus is a two-way path for information in the microcomputer system shown in Fig. 1-2.

**1.11** Permanent programs are typically stored in IC devices called _____-_____ memories.

**Solution:**

Permanent programs are typically stored in IC devices called read-only memories.

**1.12** The letters ROM stand for what type of computer memory?

**Solution:**

ROM stands for read-only memory.

**1.13** The letters RWM stand for what type of computer memory?

**Solution:**

RWM stands for read/write memory.

**1.14** Data and temporary microcomputer programs are stored in memories referred to as _____ (RAM, ROM).

**Solution:**

Data and temporary programs are stored in memories called RAM.

**1.15** Microcomputer RAM data storage is _____ (permanent, temporary).

**Solution:**

RAM storage is temporary.

**1.16** Microcomputer ROM program storage is _____ (permanent, temporary).

**Solution:**

ROM storage is permanent.

**1.17** The place information enters or leaves a computer is called a _____ (port, slot).

**Solution:**

Information enters or leaves a computer system through places called ports.

## 1.4 MICROCOMPUTER OPERATION

As an example of microcomputer operation refer to Fig. 1-3. In this example the following procedure is illustrated:

1. Press the A key on the keyboard.
2. Store the letter A in memory.
3. Print the letter A on the screen of the cathode-ray tube (CRT) monitor.

The input-store-output procedure outlined in Fig. 1-3 is a typical microcomputer system operation. The electronic hardware used in a system like that in Fig. 1-3 is quite complicated. However, the transfer of data within the system will help explain the use of the different units within the microcomputer.

The more detailed diagram in Fig. 1-4 will aid understanding of the typical microcomputer input-store-output procedure. First, look carefully at the *contents* section of the program memory in Fig. 1-4. Note that instructions have already been loaded into the first six memory locations. From Fig. 1-4, it is determined that the instructions currently listed in the program memory are:

1. INPUT data from input port 1.
2. STORE data from port 1 in data memory location 200.
3. OUTPUT data to output port 10.

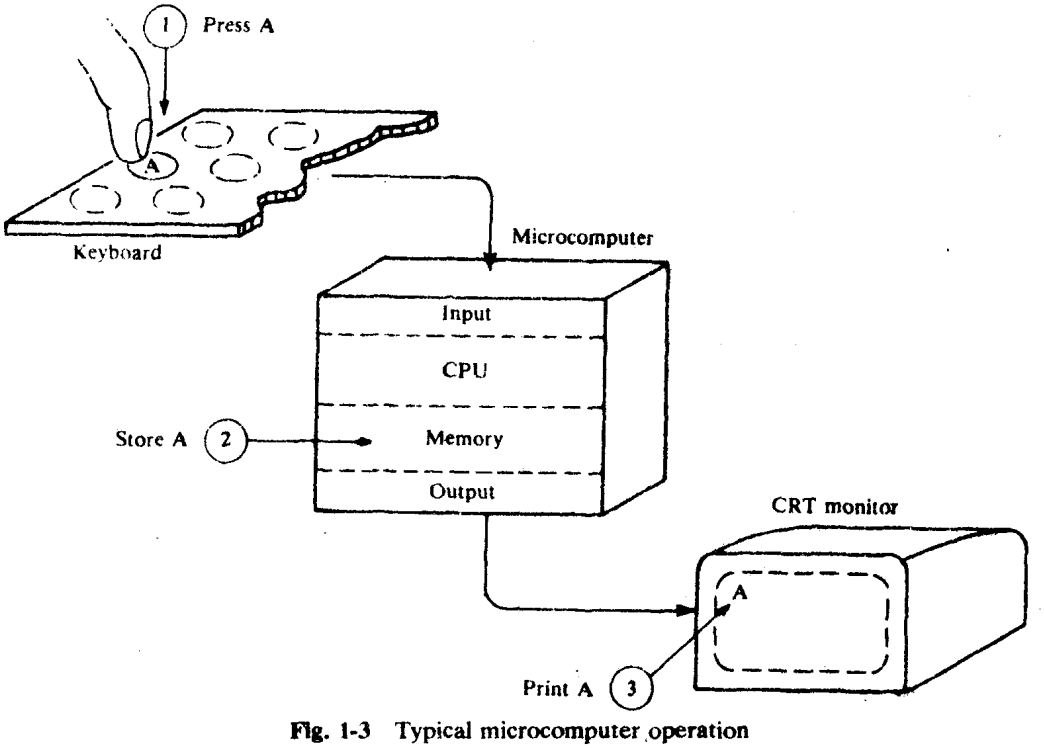


**Fig. 1-3** Typical microcomputer operation

Note that there are only three instructions in the above program. It appears that there are six instructions in the program memory in Fig. 1-4. The reason for this is that instructions are usually broken into parts. The first part of instruction 1 above was to INPUT data. The second part tells from where the data comes (from port 1). The first *action* part of the instruction is called the *operation* and the second part the *operand*. The operation and operand are located in separate memory locations in the program memory in Fig. 1-4. For the first instruction in Fig. 1-4, program memory location 100 holds the INPUT operation while memory location 101 holds the operand (port 1) telling from where information will be input.

Two new sections have been identified inside the microprocessor in Fig. 1-4. These two sections are called *registers*. These special registers are the *accumulator* and the *instruction register*.

The sequence of events happening within the microcomputer in the input-store-output example in Fig. 1-3 are outlined in Fig. 1-4. The flow of instructions and data will be followed by keying on the circled numbers in the diagram. Remember that *the microprocessor (MPU) is the center of all data transfers and operations*. Refer to Fig. 1-4 for all steps below.

Step 1 The MPU sends out address 100 on the address bus. A control line *enables* (turns on) the *read* input on the program memory IC (to read means to copy information from a memory location). This step is symbolized on Fig. 1-4 by the encircled 1.

Step 2 The program memory reads out the first instruction (INPUT data) on the data bus, and the MPU accepts this coded message. The instruction is placed in a special memory location within the MPU called the instruction register. The MPU *decodes* (interprets) the instruction and determines that it needs the operand to the INPUT data instruction.

Step 3 The MPU sends out address 101 on the address bus. The control line enables the read input of the program memory.

Step 4 The program memory places the operand (from port 1) onto the data bus. The operand was located at address 101 in program memory. This coded message (the address for port 1) is accepted off the data bus and placed in the instruction register. The MPU now decodes the entire instruction (INPUT data from port 1).

Step 5 The MPU causes port 1 to open using the address bus and control lines to the input unit. The coded form for A is transferred to and stored in the *accumulator* of the MPU.

It is important to note that the MPU always follows a *fetch-decode-execute sequence*. It first fetches the instruction from program memory. Second, the MPU decodes the instruction. Third, the MPU executes the instruction. Try to notice this fetch-decode-execute sequence in the next two instructions. Continue with the program listed in the program memory in Fig. 1-4.

Step 6 The MPU addresses location 102 on the address bus. The MPU enables the read input on the program memory using the control lines.

Step 7 The code for the STORE data instruction is read onto the data bus and accepted by the MPU in the instruction register.

Step 8 The MPU decodes the STORE data instruction and determines that it needs the operand. The MPU addresses the next memory location (103) and enables the program memory read input.

Step 9 The code for "in memory location 200" is placed on the data bus by the program memory. The MPU accepts this operand and stores it in the instruction register. The entire "STORE data in memory location 200" has been fetched from memory and decoded.

Step 10 The execute process now starts. The MPU sends out address 200 on the address bus and enables the *write* input of the data memory (to write means to copy data into a memory location).

Step 11 The MPU puts the information stored in the accumulator on the data bus (the coded form of A). The A is written into location 200 in data memory. The second

instruction has been executed. This STORE process did not destroy the contents of the accumulator. The accumulator still also contains the coded form of A.

Step 12 The MPU must fetch the next instruction. It addresses location 104 and enables the read input of the program memory.

Step 13 The "OUTPUT data" instruction code is placed on the data bus. The MPU accepts the instruction in the instruction register. The MPU decodes the instruction and determines that it needs an operand.

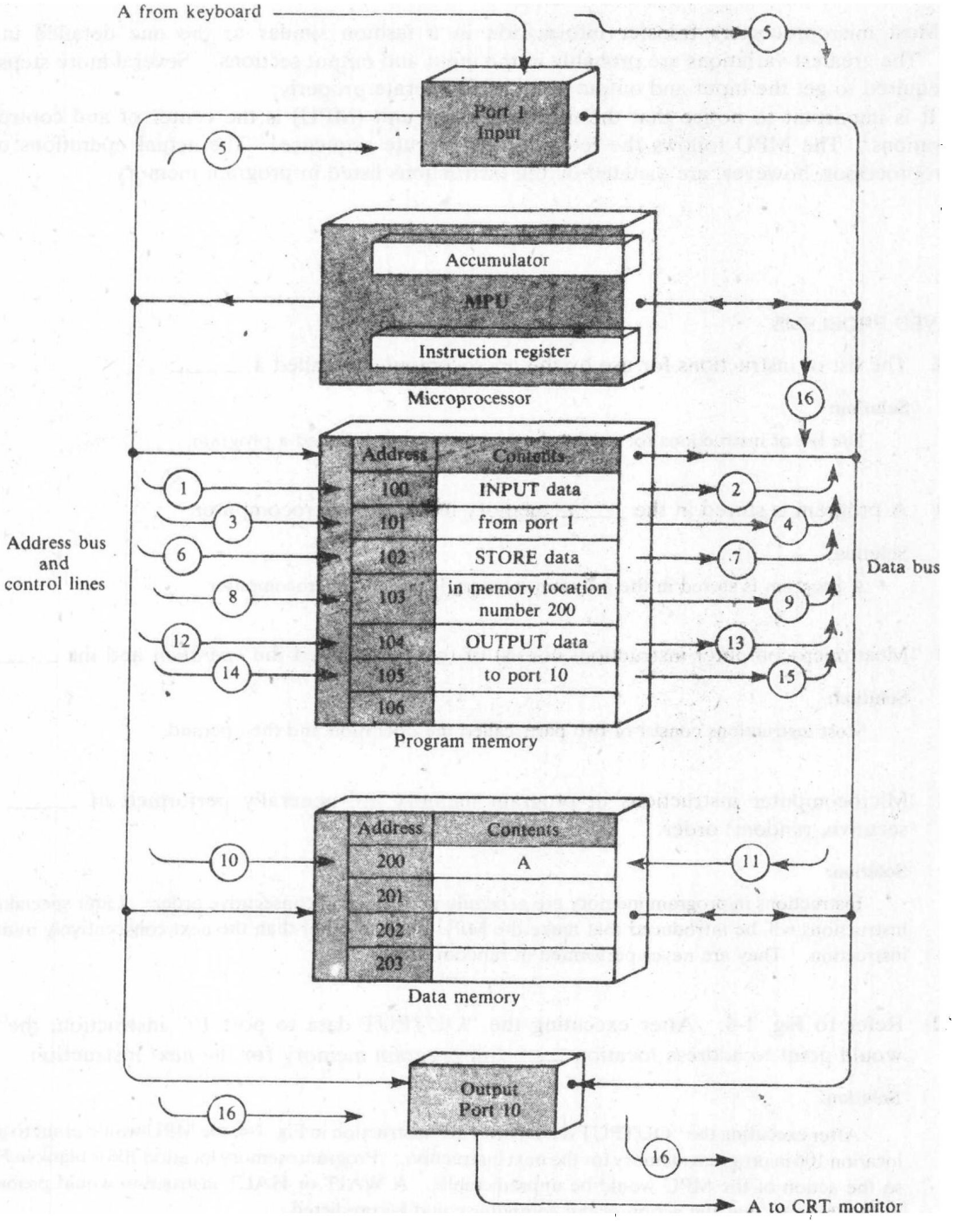


**Fig. 1-4** Step-by-step operation of a microcomputer as it executes the instructions in program memory

Step 14 The MPU places address 105 on the address bus and enables the read input of the program memory.

Step 15 The program memory puts the code for the operand "to port 10" on the data bus. The MPU accepts this code in the instruction register.

Step 16 The MPU decodes the entire instruction "OUTPUT data to port 10." The MPU activates port 10 using the address bus and control lines to the output unit. The MPU places the code for the A (still stored in the accumulator) on the data bus. The A is transmitted out of port 10 to the CRT monitor.

Most microprocessors transfer information in a fashion similar to the one detailed in Fig. 1-4. The greatest variations are probably in the input and output sections. Several more steps may be required to get the input and output sections to operate properly.

It is important to notice that the microprocessor unit (MPU) is the center of and controls all operations. The MPU follows the fetch-decode-execute sequence. The actual operations of the microprocessor, however, are dictated by the instructions listed in program memory.

## SOLVED PROBLEMS

**1.18** The list of instructions for use by the microcomputer is called a _____.

**Solution:**

The list of instructions for use by the microcomputer is called a program.

**1.19** A program is stored in the _____ memory inside the microcomputer.

**Solution:**

A program is stored in the program memory inside the microcomputer.

**1.20** Most microcomputer instructions consist of two parts called the *operation* and the _____.

**Solution:**

Most instructions consist of two parts called the operation and the operand.

**1.21** Microcomputer instructions in program memory are generally performed in _____ (consecutive, random) order.

**Solution:**

Instructions in program memory are *generally* performed in consecutive order. Later special *branch* instructions will be introduced that make the MPU jump to other than the next consecutively numbered instruction. They are never performed in random order.

**1.22** Refer to Fig. 1-4. After executing the "OUTPUT data to port 10" instruction, the MPU would point to address location _____ in program memory for the next instruction.

**Solution:**

After executing the "OUTPUT data to port 10" instruction in Fig. 1-4, the MPU would point to address location 106 in program memory for the next instruction. Program memory location 106 is blank in Fig. 1-4, so the action of the MPU would be unpredictable. A WAIT or HALT instruction would probably be placed here so that the action of the computer could be predicted.

**1.23** The letters MPU stand for _____ _____.

**Solution:**

The letters MPU stand for microprocessor unit.

**1.24** Refer to Fig. 1-4. A microcomputer instruction such as "STORE data in memory location 201" would result in the transfer of data from the MPU to location 201 in _____ memory.

**Solution:**

An instruction such as "STORE data in memory location 201" would result in the transfer of data from the MPU to location 201 in data memory.

**1.25** Refer to Fig. 1-4. A microcomputer instruction such as "STORE data in memory location 202" would result in the transfer of data from the MPU's _____ (accumulator, instruction register) to address location _____ in RAM.

**Solution:**

An instruction such as "STORE data in memory location 202" would result in the transfer of data from the MPU's accumulator to address location 202 in RAM. This data would then be contained in both RAM memory location 202 and the MPU's accumulator. The contents of the accumulator are not destroyed when data is stored.

**1.26** The _____ (read, write) process occurs when data is copied from a memory location.

**Solution:**

The read process occurs when data is copied from a memory location.

**1.27** Placing data into a storage location is a process called _____ (reading, writing) into memory.

**Solution:**

Putting data into a storage location is a process called writing into memory.

**1.28** For each instruction in program memory, the MPU goes through a _____-_____-_____ sequence.

**Solution:**

For each instruction in program memory, the MPU goes through a fetch-decode-execute sequence. Some books call this the *locate-read-interpret-execute cycle.*

**1.29** Refer to Fig. 1-4. After step 16, when the instruction "OUTPUT data to port 10" is complete, what data is contained in the accumulator of the MPU?

**Solution:**

The accumulator still contains the code for A. Reading data from a register or memory location only copies the information that is there and does not destroy the data.

**1.30** Refer to Fig. 1-4. After step 16, do the instructions in memory locations 100 through 105 still exist?

**Solution:**

Yes. Reading instructions does not destroy the contents of that memory location.

## Supplementary Problems

**1.31** In electronics, the letters IC stand for _____ _____. *Ans.* integrated circuit

**1.32** In electronics, the letters LSI stand for _____ _____ _____. *Ans.* large-scale integration

**1.33** In computers, the letters CPU stand for _____ _____ _____. *Ans.* central processing unit

**1.34** An LSI IC that has most of the capabilities of a computer's CPU is called a _____.
*Ans.* microprocessor

**1.35** In microcomputers, the letters MPU stand for _____ _____. *Ans.* microprocessor unit

**1.36** Microcomputers that perform only one or two tasks are said to be _____ (general-purpose, dedicated) computers. *Ans.* dedicated

**1.37** A classical computer organization would probably list what five major units?
*Ans.* input, control, arithmetic, memory, output

**1.38** A list of computer instructions is classified as _____ (hardware, software). *Ans.* software

**1.39** Information that is manipulated within a computer is called _____ (data, numerical information).
*Ans.* data

**1.40** A person who writes lists of instructions for a computer is called a _____. *Ans.* programmer

**1.41** Permanent storage of a program inside a microcomputer would probably be done in a _____ (RAM, ROM). *Ans.* ROM

**1.42** The _____ (RAM, ROM) is a widely used IC device used in microcomputers as a read/write memory.
*Ans.* RAM

**1.43** Refer to Fig. 1-2. The instructions stored in the program memory would be _____ (permanent, temporary). *Ans.* permanent (stored in ROM)

**1.44** The actual electronic hardware needed to implement the system shown in Fig. 1-3 would be quite _____ (complex, simple). *Ans.* complex

**1.45** Refer to Fig. 1-4. After step 16 is complete, the MPU will attempt the _____ (decode, fetch, execute) procedure. *Ans.* fetch

**1.46** Refer to Fig. 1-4. The MPU accesses a specific memory location by using the _____ bus.
*Ans.* address

**1.47** Refer to Fig. 1-4. Coded information is transferred from the MPU's accumulator to a storage location in data memory using the _____ bus. *Ans.* data

**1.48** If the MPU fetched and decoded an instruction saying "STORE data in memory location 205," the data would come from the _____. *Ans.* accumulator (within the MPU)

**1.49** A microcomputer contains at least an input unit, an output unit, an MPU, and a program and data _____. *Ans.* memory

**1.50** A temporary read/write memory is designated by either the three letters RWM or _____.
*Ans.* RAM